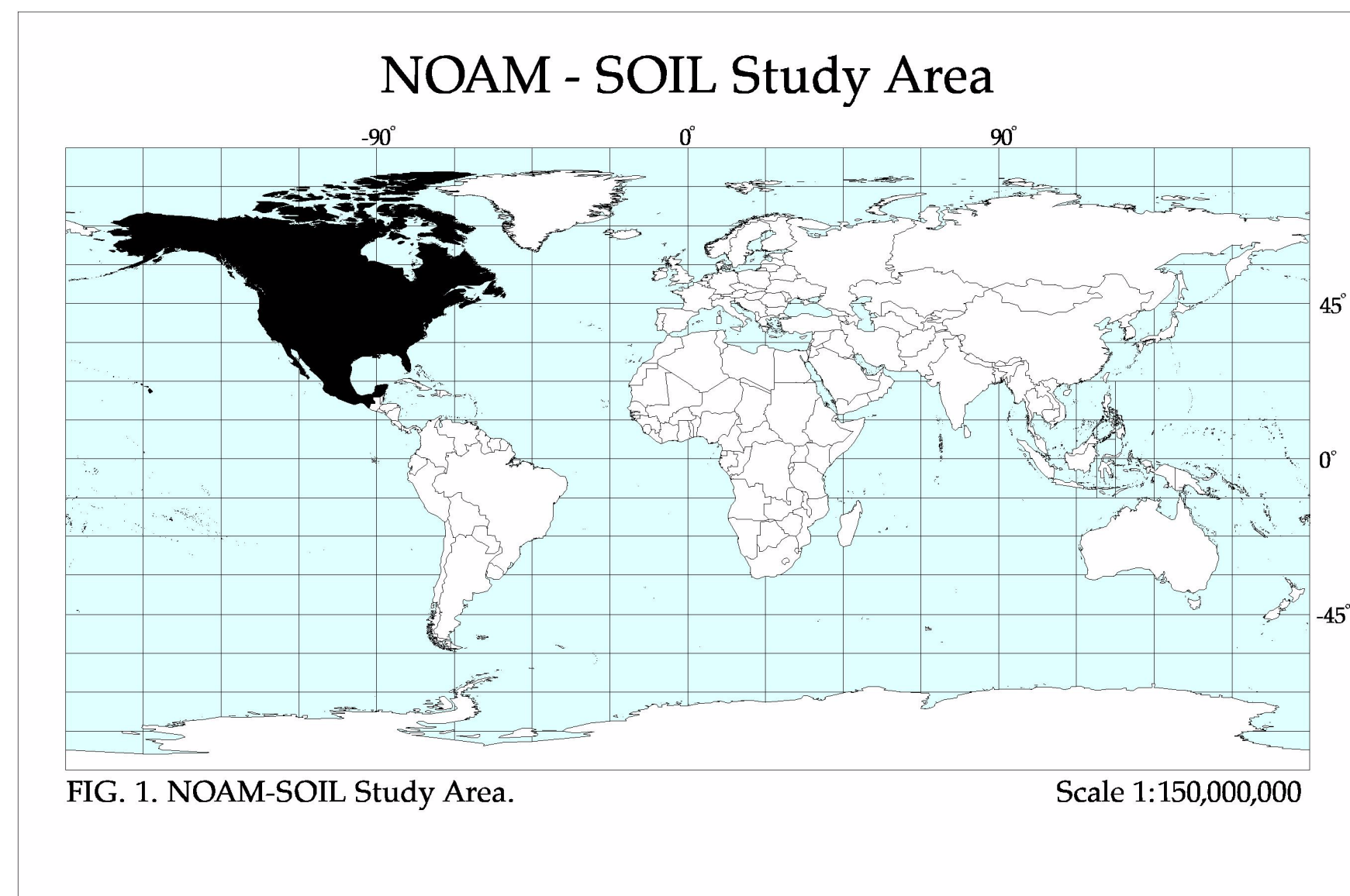


A North American Multi-Layer Soil Characteristics Dataset for Climate and Hydrology Applications: NOAM-SOIL



ABSTRACT

The climate and hydrology modeling communities have developed increasingly sophisticated parameterizations of the interaction between the land surface and the atmosphere in so-called soil-vegetation-atmosphere transfer schemes (SVAT's). These process descriptions require an understanding of the surface and subsurface nature of the soil environment. Soil moisture is the key state variable controlling the partitioning of atmospheric heat and moisture forcing at the land surface. Knowledge of the amount and location of water in the soil is required across a range of space and time scales to determine water and energy balances. A prerequisite for correctly modeling soil moisture is a knowledge of soil physical and hydraulic properties. The development of the North American Multi-Layer Soil Characteristics Dataset (NOAM-SOIL) Project began in 1998 by the Penn State Earth System Science Center and the USDA-Natural Resources Conservation Service, and is slated for completion in 2001 (Figure 1).



NOAM-SOIL is the natural continental extension of CONUS-SOIL, a value added version of the USDA State Soil Geographic Data Base (STATSGO) for the lower 48 states, previously published by Penn State (http://www.essc.psu.edu/soil_info/). NOAM-SOIL will include multi-layer information for soil textural class, rock fragment class, depth-to-bedrock, bulk density, porosity, rock fragment volume, sand, silt, and clay fractions, and available water capacity. A peer-review panel representing Agri- and Agri-Food Canada, USDA, USGS, and INEGI-Mexico are contributing data. In this poster, we present an initial version of the NOAM-SOIL dataset.

BACKGROUND

Over the past several decades the climate and hydrology modeling communities have developed increasingly sophisticated parameterizations of the interaction between the land surface and the atmosphere in so-called soil-vegetation-atmosphere transfer schemes (SVATS). A major requirement of these process descriptions is an understanding of the surface and subsurface nature of the soil environment. The soil controls the downward movement of water in the subsurface and the amount of water available for evapotranspiration. Knowledge of soil physical and hydraulic properties is, therefore, a key element in correctly modeling land surface atmosphere exchange processes. SVAT modelers, recognizing the importance of soil and soil hydrology, have explicitly incorporated these processes in their models.

Most of the physically-based soil hydrology models are based on some form of Darcy's law of water movement

which relates the flux of downward infiltrating water (q) moving proportionally to the forces of gravitation and the matric potential (y):

$$(1) \quad q = K \frac{\partial}{\partial z}(\Psi) + K$$

where (z) is depth and (K) is the hydraulic conductivity. Darcy's equation can be combined with the equation for continuity

$$(2) \quad \frac{\partial \theta}{\partial t} = - \frac{\partial}{\partial z}(q)$$

where (q) is the volumetric soil-water content and (t) is time, to fully account for the diffusion and gravitation components of water movement. The result is formally known as the Richards equation:

$$(3) \quad \frac{\partial}{\partial t} \theta(z) = - \left(\frac{\partial}{\partial z} \times \left[K(q) \frac{\partial}{\partial q} \Psi(q) \frac{\partial q}{\partial z} \right] \right) - \frac{\partial}{\partial q} K(q) \frac{\partial q}{\partial z}$$

which describes the flow of water in the unsaturated zone as a function of soil water content and its vertical gradient. Solution of Eq. (3) requires an understanding of the water retention characteristic: the relationship between the water content, (q), the matric potential, (y), and the hydraulic conductivity, (K).

Laboratory and field methods for determining these soil hydraulic properties are time consuming and expensive. Peto-transfer functions (PTF's) have been developed to derive hydraulic characteristics from data (e.g. soil texture, particle-size distribution, bulk density, porosity) gathered in the course of traditional soil surveys (Tietje and Tapkenhins, 1992; Brooks and Corey, 1964; Campbell, 1974; Clapp and Hornberger, 1978; van Genuchten, 1980; Arya and Paris, 1981; Kern, 1995b; Saxton et al., 1986; Rawls et al., 1991; Vereecken et al., 1990).

Despite the implementation of soil hydrologic processes in SVATS there has been a dearth of spatial information on soil physical and hydraulic properties for regional climate and hydrology applications. Webb et al. (1993) produced a global data set of soil profile physical properties by combining the Food and Agriculture Organization of the United Nations/United Nations Educational, Scientific and Cultural Organization (FAO/UNESCO) Soil Map of the World with the World Soil Data File of Zolber (1986). Kern (1995a) used the United States Department of Agriculture Natural Resources Conservation Service (USDA-NRCS) National Soil Geographic Database (NATSGO) or Major Land Resource Areas (MLRA's) as a geographic base and the 1992 National Resources Inventory (NRI) and the associated Soil Interpretations Record (SIR) to estimate, for the continuous 48 United States, geographic patterns of soil water-holding capacity. Lathrop et al. (1995) reported the use of STATSGO available water holding capacity data in a forest ecosystem model for the northeast United States. Zheng et al. (1996) compared available water capacity estimated from topography to STATSGO data in Montana.

The development of CONUS-SOIL (Miller and White, 1998) was an initial step in developing a practical soil information product that could be easily applied in regional climate and hydrology modeling applications. Its success and numerous

requests from the environmental modeling community, has prompted us to develop a similar dataset that would include Canada and Mexico, essentially a 1-km multi-layer soil characteristics dataset for North America (NOAM-SOIL).

OBJECTIVES

1) Development of a 1-km Multi-Layer Soil Characteristics Dataset for North America designed for use in regional scale climate, hydrology, and environmental modeling applications.

2) Delivery of this dataset, including detailed descriptions of our methods and complete documentation to the modeling community via the World Wide Web.

METHOD

Data Resources

The development of a North American soils dataset entails combining U.S., Canadian, and Mexican soil data resources into a unified structure. This section briefly describes the nature of these data sources.

U. S. State Soil Geographic Database (STATSGO)

The USDA-NRCS, through the National Cooperative Soil Survey (NCSS), develops soil geographic databases at three scales: local, regional, and national. At the regional level, the State Soil Geographic Data Base (STATSGO) was published in 1994 for use in river basin, multi-county, multi-state, and state resource planning. This database was created by generalizing available soil-survey maps, including published and unpublished detailed soil surveys, county general soil maps, state general soil maps, state major land resource area maps, and, where no soil survey information was available, Landsat Imagery (Reybold and Teselle, 1989).

STATSGO consists of georeferenced digital map data and associated digital tables of attribute data. The compiled soil maps were created using the USGS 1-degree by 2-degree topographic quadrangles (1:250,000 scale, Albers Equal Area projection) as base maps which were then merged on a state basis. Each state and the Commonwealth of Puerto Rico has been mapped. The District of Columbia is included with the data for Maryland. The full STATSGO database is available from the NRCS on CD-ROM and is also available online over the Internet (USDA, 1994).

Map units in STATSGO are comprised of phases of soil series and their associated component percentages. A soil series is the lowest level in the U.S. system of taxonomy (Soil Survey Staff, 1993) and the most homogeneous with regard to properties. A phase of a soil series is based on attributes and factors that affect soil management. Map unit composition was derived from a statistical analysis of transects across detailed soil survey maps. Percentages of the map unit components were based on the length of the map units crossed. The total number of transects was based on the size, number, and complexity of the detailed soil map delineations. Details of the exact procedures for determining map-unit composition may be found in the STATSGO Data Users Guide (USDA, 1994).

Soil Landscapes of Canada (SLC)

The Canadian portion of NOAM-SOIL is derived from the nationally merged Soil Landscapes of Canada (SLC) and associated landscape components and appropriate Soil Layer File records (Shields et al., 1991; Tarnocai et al., 1996). The SLC as modified for development of the Soil Carbon Data Base of Canada consists of 1:1,000,000 scale soil polygons which may have 3 to 10 different soil landscape components, each with an associated component percentage based on the area occupied by each component within the soil landscape map unit concept. SLC was prepared from existing soil surveys in Canada, generalized by provincial soil scientists to a common scale of 1:1,000,000.

Soil Layer File component attributes associated with SLC polygons that are of value to NOAM-SOIL include: soil development (Canadian Taxonomic classification), percent composition, vegetative cover/land use, parent material, coarse (rock) fragment content, rooting depth, bulk density, texture and drainage class. NOAM-SOIL characteristics data calculations are made for appropriate Soil Layer File records. These are then associated with appropriate SLC components, weighted for component percentages and mapped to individual SLC polygons.

Soil Map of Mexico

The Mexican portion of NOAM-SOIL is derived from the 1981 1:1,000,000 scale Soil Map of Mexico developed by Instituto Nacional de Estadística, Geografía e Informática - INEGI (INEGI, 1981). This map was digitized by USDA-NRCS and EROS Data Center in 1993-1994. Attributes encoded and associated with each soil map polygon include: primary, secondary, and tertiary FAO/UNESCO soil group and percent composition, surface texture class, physical phase, chemical phase, and map symbol. Basic soil physical and chemical attributes of approximately 1500 soil pedons (published with the 1:250,000 scale Soil Map of Mexico and key-entered into a digital relational data base by the USDA-NRCS National Soil Survey Center (NSSC) in 1994 (Waltman et al., 1997).

Mexican pedon attributes include: pedon identifier, FAO-UNESCO soil group, chemical phase, physical phase, horizon designator, horizon depths, organic carbon, cation exchange capacity, percent sand, silt, and clay, estimated rock fragment content, pH, CaCO₃, and derived (modeled) bulk density. The dominant soil group physical property value from the pedon database is then associated with the appropriate primary, secondary, and tertiary soil groups in the 1:1,000,000 Soil Map of Mexico using the FAO/UNESCO soil group codes. These values are then weighted according to the percent composition provided by the 1:1,000,000 Soil Map of Mexico estimates in the development of the desired NOAM-SOIL characteristics for Mexico.

Data Analysis and Processing

A major challenge in developing a soil dataset such as NOAM-SOIL is the disparate nature of the component soil survey products for each country. Although somewhat similar in general data structure, the STATSGO, SLC, and Soil Map of Mexico datasets were individually developed under different circumstances and using different source materials and technologies. Our goal for the development of the data structure and specifications for NOAM-SOIL is to ensure that the final product contains the best possible combined information from these primary sources while minimizing the inherent limitations set by original development methods.

To meet this goal, we are determining the overall depth-of-soil that can be reliably represented and the number of individual soil layers that can be created from the combined data. All work is conducted on the native vector formats of the source dataset coverages and their associated attributes (Figure 2). Each targeted soil property listed in Table 1. is processed individually with "joins" between datasets made on a layer basis to ensure continuity at international boundaries. A complete North American grid map coverage is created with individual vector coverages maintained for each country. Additional gridded datasets for each of the soil physical and hydraulic properties are subsequently created.

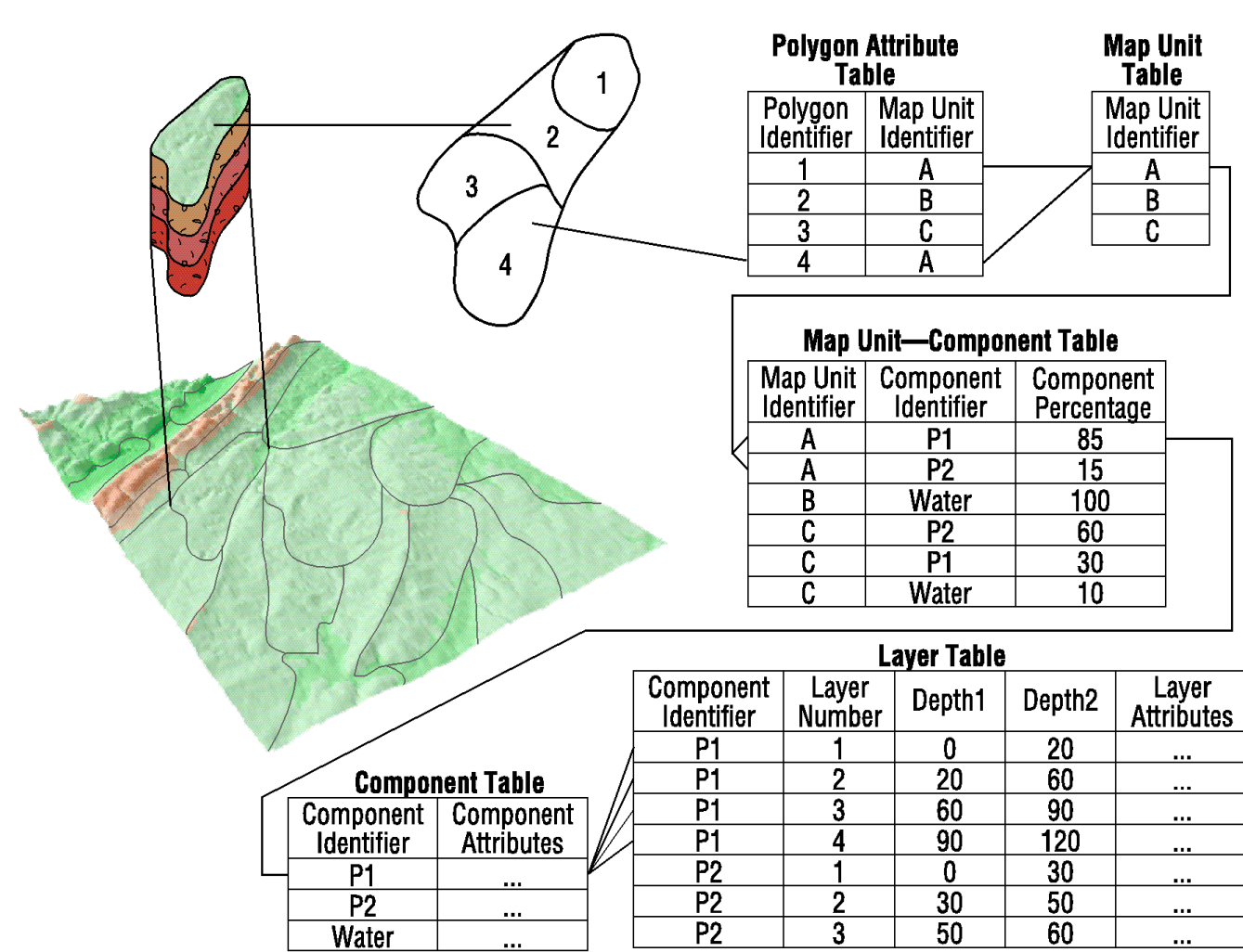


Figure 2. Schematic diagram of the proposed NOAM-SOIL dataset structure

Data Products

A key element in the success of any dataset development project for modeling applications is the development of an end-product that meets the users specific needs. Within the climate and hydrology modeling community, a range of spatial data handling tools and skills may be found. Some modelers use GIS technology and prefer to work with the vector data structure and perform their own grid and map projection conversions. Others may prefer to work with a previously gridded map product imported into their GIS environment. Finally, many climate and hydrology modelers have their own internal format conventions and would prefer to ingest a simply formatted data set that can be read with commonly available software or computer languages. To meet the needs of the latter two groups, the facilities of the Arc/Info GIS software will be used to rasterize each of the previously described soil physical and hydraulic properties (Table 1) from the vector (polygon) map coverages to a 1-km resolution grid. A summary of the available data formats and map projections is provided in Table 2.

Table 1. Soil physical and hydraulic properties to be included in NOAM-SOIL

Soil Physical and Hydraulic Properties	
Soil Texture	
Rock Fragment Class	
Depth-to-Bedrock	
Bulk Density	
Porosity	
Rock Fragment Volume	
Sand, Silt, Clay Fractions	
Available Water Capacity	

Table 2. NOAM-SOIL Data Formats

Formats	Lambert Azimuthal	Albers Equal Area	Latitude/Longitude
Arc/Info Polygon	*	*	*
Arc/Info Grid	*	*	*
Binary Array Grid	*	*	*

WWW Interface

The World Wide Web (WWW) provides an ideal medium for delivery of spatial data products as demonstrated with the WWW server for CONUS-SOIL (http://www.essc.psu.edu/soil_info/) which allows easy access to all elements of the data set, including: all spatial and tabular data, documentation, and cartographic products. As similar approach will be used to deliver the NOAM-SOIL products.

Peer Review Panel

As an extra measure to ensure the highest quality the NOAM-SOIL data set is being reviewed and tested by a peer review panel to assess appropriateness of method and accessibility. The review panel is comprised of Drs. Hari Eswaran and Norman Bliss representing USDA and the US Dept. of Interior; Dr. Charles Tarnocai representing Agriculture and Agri-Food Canada; and Dr. Francisco Orozco-Chavez representing Instituto Nacional de Estadística, Geografía e Informática (INEGI). Drs. Tarnocai and Orozco-Chavez serve as the author/contributors of the original source materials used to develop the Canadian and Mexican portions of NOAM-SOIL.

RESULTS

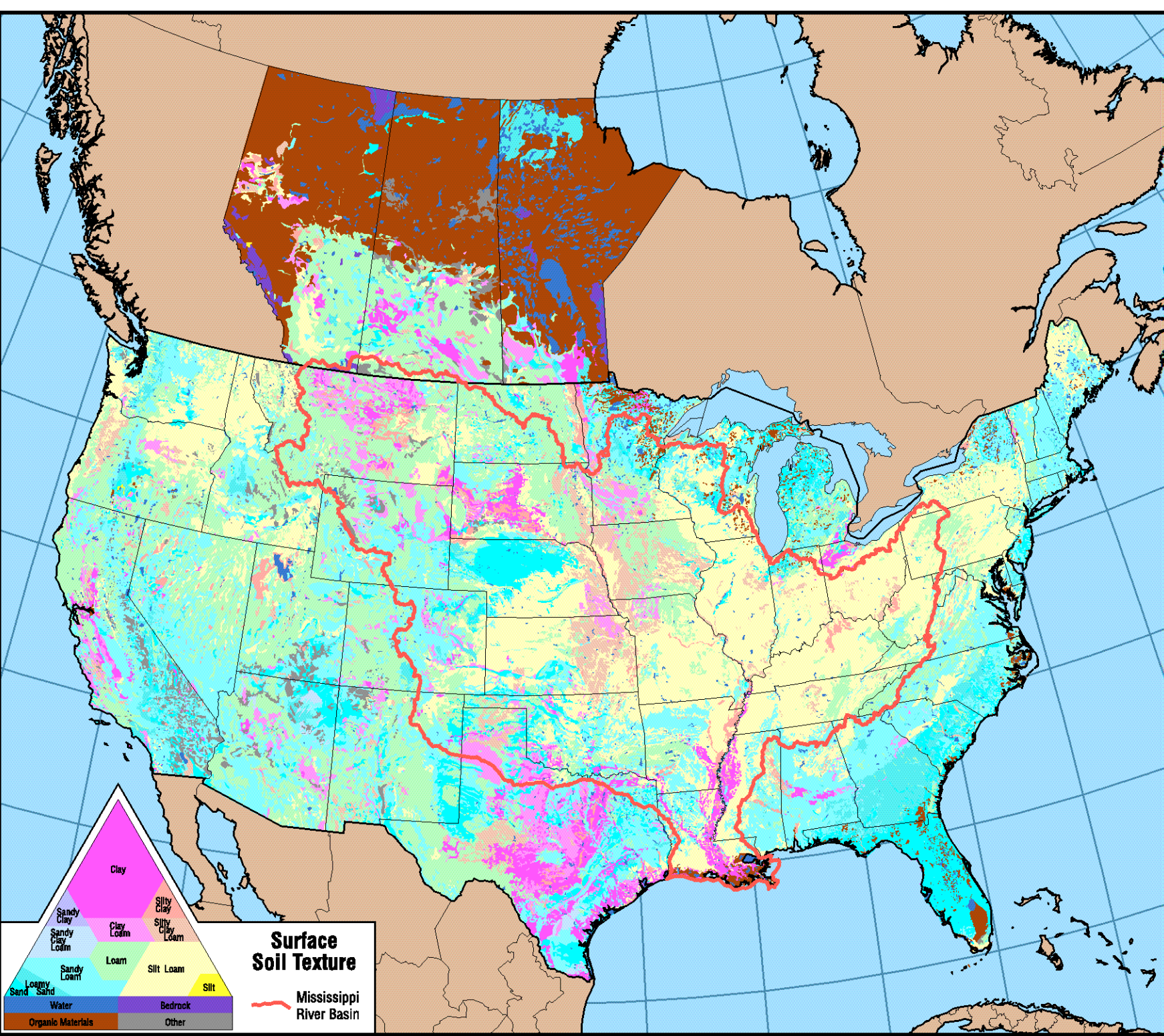


Figure 3. Dominant soil surface texture for Alberta, Saskatchewan, and Manitoba, Canada and the lower 48 United States featuring the Mississippi River basin.

Year 1 1998-1999 Assemble data. Devise a consistent approach for data reduction.

An example of Year 1 products is illustrated in Figure 3 for portions of Canada and the lower 48 United States prepared



in cooperation with Dr. Charles Tarnocai and Barbara Lacelle of Agri- and Agri-Foods Canada.

FUTURE WORK

Year 2 1999-2000 Continued data processing and refinement. Complete and deliver first several data coverages. Enhance existing WWW and database interface for access and download of soils information.

Year 3 2000-2001 Complete data processing, consistency and quality checks. Complete WWW interface for access and delivery of NOAM-SOIL to the user community.

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REFERENCES

- Arya, L.M. and J.F. Paris, 1981. A physicoempirical model to predict the soil moisture characteristic from particle-size distribution and bulk density data. *Soil Soc. Sci. Am. J.* 49, 1100-1105.
- Brooks, R.H. and A.T. Corey, 1964. Hydraulic properties of porous media. *Hydrology Paper 3*. Colorado State University, Fort Collins, CO.
- Campbell, G.S., 1974. A simple method for determining unsaturated conductivity from moisture retention data. *Soil Sci. Soc. J.* 38, 311-314.
- Clapp, R.B. and G.M. Hornberger, 1978. Empirical equations for some soil hydraulic properties. *Water Resour. Res.* 14, 601-604.
- INEGI, 1982. 1:1,000,000 and 1:250,000 Soil Maps of Mexico. Unidad de Clasificación FAO/UNESCO 1970 (Modificada Por DGGTENA). INEGI.
- Kern, J.S., 1995a. Geographic patterns of soil water-holding capacity in the contiguous United States. *Soil Sci. Soc. Am.* 59, 1126-1133.
- Kern, J.S., 1995b. Evaluation of soil water retention models based on basic soil physical properties. *Soil Sci. Soc. Am.* 59, 1134-1141.
- Lathrop, R.G., J.D. Almer, and J.A. Bognart, 1995. Spatial variability of digital soil maps and its impact on regional ecosystem modeling. *Ecol. Model.* 82, 1-10.
- Miller, D.A. and R.A. White, 1998. A Conterminous United States Multi-Layer Soil Characteristics Data Set for Regional Climate and Hydrology Modeling. Earth Interactions, 2. [Available on-line at <http://Earth-Interactions.org>]
- Rawls, W.J., T.J. Gbik, and D.L. Brakensiek, 1991. Estimating soil water retention from soil physical properties and characteristics. *Adv. Soil Sci.* 16, 213-234.
- Reybold, W.U., and G.W. Teselle, 1989. Soil geographic data bases. *J. Soil and Water Con.* 43, 226-229.
- Saxton, K.E., W.J. Rawls, J.S. Romberger, and R.I. Papendick, 1986. Estimating generalized soil water characteristics from texture. *Soil Sci. Soc. Am. J.* 50,1031-1036.
- Shields, J. and Others, 1991. Soil Landscapes of Canada. Agriculture Canada, Canadian Soil Information System (CanSIS). Ottawa, Canada.
- Soil Survey Staff, 1993. Soil Survey Manual. U.S. Department of Agriculture Handbook No. 18. U.S. Government Printing Office, Washington, DC, 437 p.
- Soil Survey Staff, 1975. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. United States Department of Agriculture Handbook No. 436. U.S. Government Printing Office, Washington, DC, 754 p.
- Tarnocai, C., and B. Lacelle, 1996. The Soil Organic Carbon Digital Database of Canada. Research Branch, Agriculture and Agri-Food Canada, Ottawa, Canada.
- Tietje, O. and M. Tapkenhins, 1992. Evaluation of pedo-transfer functions. *Soil Sci. Soc. Am. J.* 57:1088-1095.
- USDA, 1994. State Soil Geographic Database (STATSGO) Data Users Guide. USDA Soil Conservation Service Misc. Pub. No. 1492. U.S. Government Printing Office, Washington, DC, 88 p.
- Van Genuchten, M.Th., 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Sci. Soc. Am. J.* 44:892-898.
- Vereecken, H., J. Maes, and J. Feyen, 1990. Estimating unsaturated hydraulic conductivity from easily measured soil properties. *Soil Sci. Soc. J.* 54:149-152.
- Waltman, S.W., B. Lacelle, C. Tarnocai, N.B. Bliss, and F. Orozco-Chavez, 1997. Soil Organic Carbon Map and Database for North America. 89th Annual Meeting American Society of Agronomy Abstracts, October 26-30, 1997. pp. 259.
- Webb, R.S., C.E. Rosanow, and E.R. Levine, 1993. Specifying land surface characteristics in general circulation models: Soil profile data set and derived water-holding capacities. *Glob. Biogeo. Cycles* 7, 97-108.
- Zheng, D., E.R. Hunt, Jr., and S.W. Running, 1996. Comparison of available soil water capacity estimated from topography and soil series information. *Land. Ecol.* 11, 3-14.
- Zolber, L. 1986. A world soil file for global climate modeling. NASA Tech. Memo. 87802. NASA, 33 pages.